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INFLUENCE OF CALCULATION AREA ON WAVE PREDICTION FOR MARINE WORKS IN THE PACIFIC OCEAN

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Abstract

For marine constructions, it is highly important to obtain reliable wave predictions for safety operation and workability judgment. Advanced wave prediction method based on WAM model has recently been utilized in many marine construction sites. However, accuracy of the wave prediction under mild wave climate is not clear. This study investigates optimal Pacific domain of the WAM model based on the comparison between hindcast calculation and field data. GPV wind data (GSMgl,GSMjp) from the Japan Meteorological Agency is inputted to the WAM model. The wave prediction results of some domain in the Pacific Ocean are compared with the wave measurement results of field data. The influence on wave prediction on calculation domain is clear for marine works in the Pacific Ocean.

Key words: Wave prediction accuracy, WAM, marine works, The Pacific Ocean

1. Introduction

For marine constructions involving offshore works, since the wave condition has a great influence over the safety operation and workability judgment, the development and utilization of the wave observation has been carried out. In addition, the use of a sophisticated wave estimation model for workability judgment and real-time wave estimation system has also been constructed.
However concerning the accuracy of the wave estimation model, there are many case studies focusing on the high waves caused by the weather disturbance, whereas there are only few case studies about the forecast accuracy of waves with the height of about 1m or less focusing on the feasibility of marine construction.
Along the Pacific Coast, it is desirable to expand the computational domain as much as possible, because of the frequent undulation from the distant. However since the expansion of the calculation area also leads to the increase in the calculation load, the computational domain has not yet been sufficiently studied even in the wave predication system and the creation of long-term wave database. On the other hand, in recent years, with the improvement in the computer performance and the sophistication in the computational methods, the possibility of the calculation even for the larger calculation area can be expected.
In this study, focusing on the calculation area of the Pacific Ocean, the wave estimation using WAM model which inputs the 6-hour sea surface wind data of Japan Meteorological Agency GPV (GSM global, GSM Japan region), GPS wave meter was conducted and the results are compared with NOWPHAS (Nationwide Ocean Wave information network for Port and HArbourS), with the aim of clarifying the forecast accuracy.

2. Calculation Condition

In order to verify the effect of the domain size in the Pacific Ocean, five domains are used as defined in Table 1 and Figure 1. The wind data for WAM model can be obtained from GSMjp (grid size 0.20 ° for domain1) or GSMgl (grid size 0.50 ° for domain2-5) provided by Japan Meteorological Agency (JMA).

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Consistent grid system is used in WAM and GPV modeling, and a simple linear interpolation is used to connect the domain 2-5 with domain 1. Figure 2 shows the calculation flow from the data input to the prediction result output.

Although the global wave GPV of the Japan Meteorological Agency is in the range up to 75°S, since the area occupied between the latitude 70°S-75°S is small, it is necessary to reduce the time increment as the distance of longitude decreases. As we confirmed that there is no significant difference on the Japan coast by comparing with the domain 5, the southernmost point was set to 70°S latitude of domain 5.

Table 1. Setting parameters of WAM model

Domain	domain1	domain 2	domain 3	domain 4	domain 5
North latitude	20°～50°	0°～60°		-40°～60°	-70°～60°
East longitude	120°～150°	117°～201°	117°～295°		
Minimum frequency	0.042Hz				
Frequency division number	35				
Direction division number	16				
Depth	Deep condition				
Spatial resolution	0.1°	0.5°			
Δt	300s	900s			
Wind data interval	3600s				

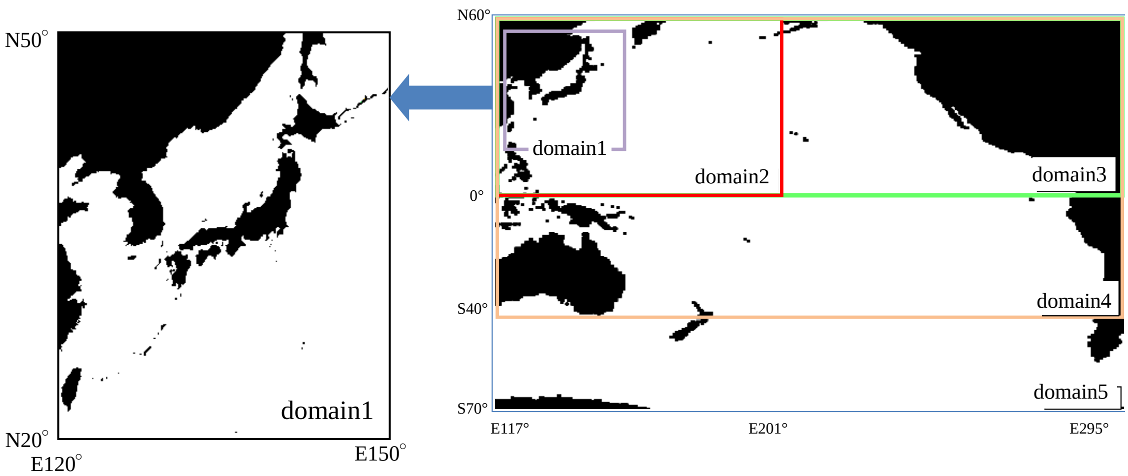


Figure 1. Calculation domain.

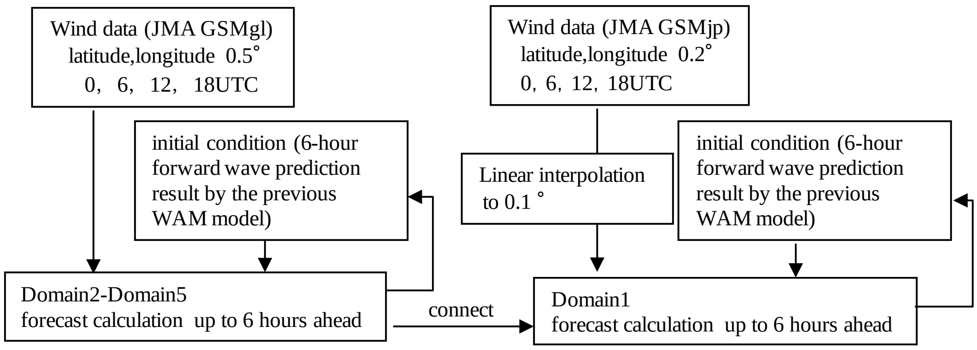


Figure 2. Calculation flow.

3. Observation data

Accuracy validation of the WAM was carried out with using NOWPHAS observed data. The Nationwide Ocean Wave information network for Ports and HArbourS (NOWPHAS) is the wave information network in Japan, conducted by few Japanese organizations. The NOWPHAS data includes the data from wave gauges at 69 points over Japan, and the wave information at 66 points is available in the website. In this study, we used two kinds of observation data: (1) GPS buoys (water depth 100 - 300 m) and (2) coastal submarine gauge (water depth 20 - 50 m). Figure 3 shows the location of observation points.

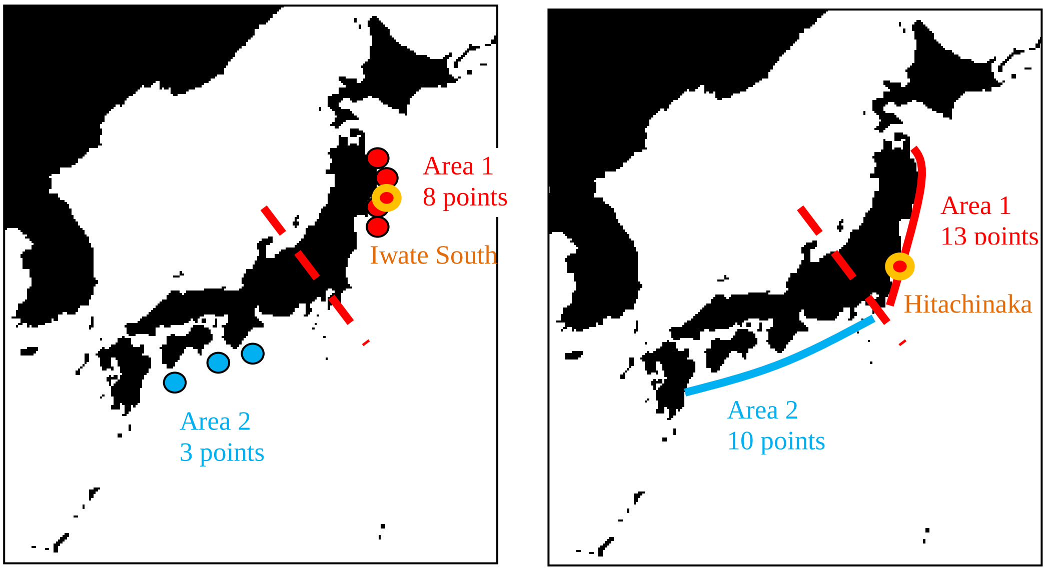


Figure 3. GPS buoy, seabed sensor position
On the left side – Figure 3a; On the Right side – Figure3b

4. Case Study for deep water area

4.1. *Time series comparison by domain*

Figure 4 shows the time series comparison between the results of the WAM model and GPS buoy data in 2008.
When domain1 is set as the calculation region, both significant wave height and the wave period are underestimated for the observed data. This is probably because the Pacific Ocean side has waves propagating from outside this area.
Domain 2 is the area expanded to the northwest Pacific Ocean, the accuracy is found to be improved both in the wave height and the wave period. However this area is sufficient in targeting the wave height and in the summer season the wave period is found to be underestimated, suggesting that there is further wave propagation from outside this area.
Domain 3 is the area expanded to the northeastern pacific area, but no significant difference is recognized compared with domain 2. This result suggests that the influence of the Northeast Pacific domain on the waves on the Pacific side of Japan is small.
Domain 4 is the area expanded to the southern hemisphere, where accuracy improvement of wave period prediction in the summer season is seen. In the domain 5 including the storm area of 40°S to 70°S in the southern hemisphere, the observation value and the predicted value almost agree with each other, but in the Summer season, the tendency of overestimation of the wave height is found.

4.2. *Correlation comparison by domain*

Figure 5 shows the correlation between the results of the observation data and WAM (domain 5) of the significant wave height and the wave period off the southern part of Iwate Prefecture (Marked as orange circle in Figure 3a). The regression coefficient of 1.0 illustrates a match between the observed value and WAM model. From the Figure 5 the regression coefficient of the wave height is calculated to be 0.87 and that of the wave period is 0.98, which means that the WAM model underestimates the wave height.

For all the points as shown in Figure 3, the regression coefficients of the wave height and the regression coefficients of the wave period at all the points are summarized as a plot in Figure 6. Domain 1 is underestimated as a whole below 0.8, and the regression coefficient approaches 1.0 with the widening of the calculation domain. Lack of the notable difference in the domain2 and domain3 infers the negligible influence of the North-East Pacific ocean. Domain4 and domain5 suggests that the widening of domain2 and domain3 in the southern hemisphere could improve the accuracy of the wave period in the area2 (Figure3a).

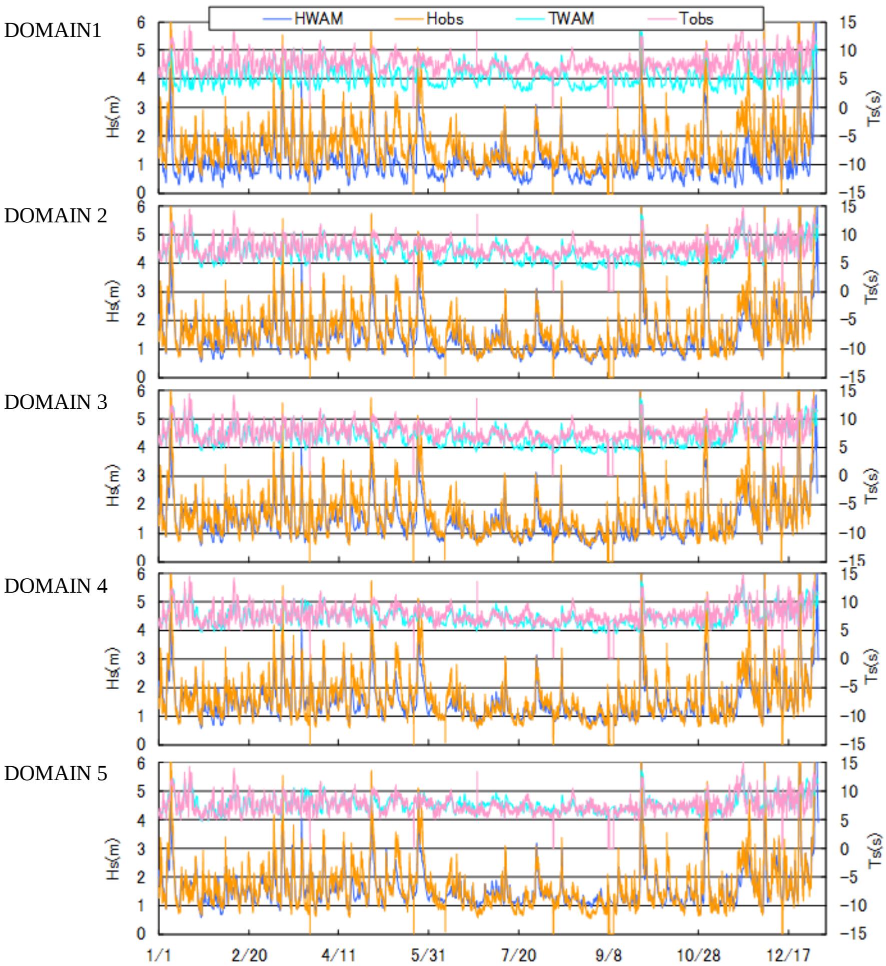
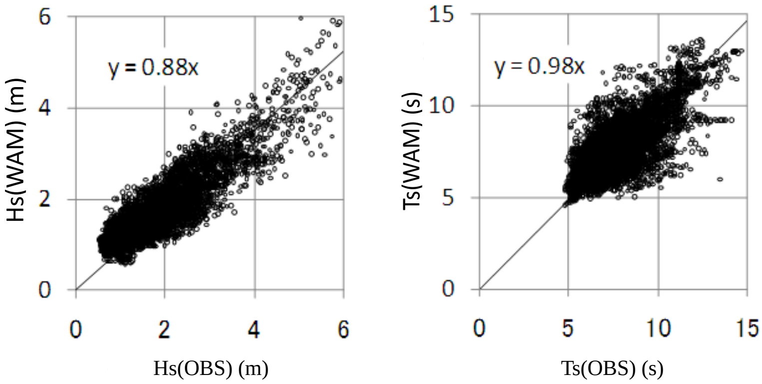
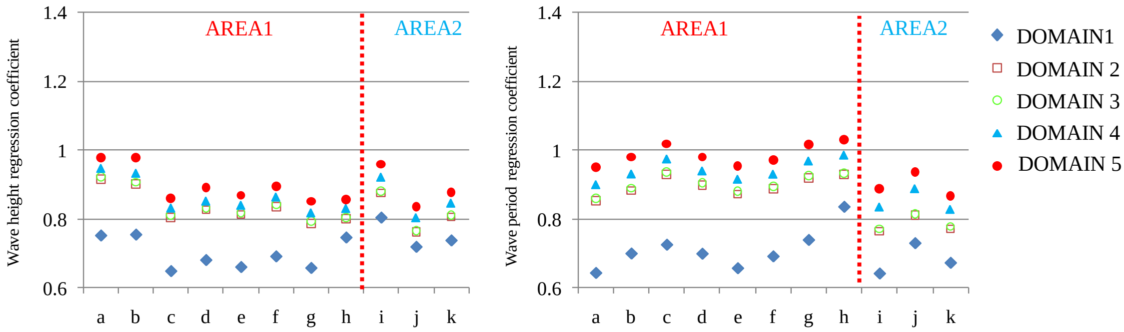


Figure 4. Time series of comparison between WAM and GPS buoy data in 2010



(a) wave height correlation (b) wave period correlation

Figure 5. Correlation diagram between field observation and calculated value



(a) wave height correlation (b) wave period correlation

Figure 6. Regression coefficient between field observation and calculated value

5. Case Study for coastal area

5.1. *Time series comparison by domain*

A comparison between the results of the observation data and the WAM at Hitachinaka (water depth 30.3 m) as a representative point of the coastal zone is shown in Figure 7.
In domain 1, the observation value of both the significant wave height and the wave period is underestimated (just like the GPS buoy of the South of Iwate Prefecture), resulting in the insufficiency in the calculated area. As compared with this domain, the domain 2 and 3 is observed to be in good agreement and the wave height is found to be improved whereas the wave period is underestimated in summer. These inferences suggest the shortage of the calculation domain in the south. In the domain 4 and 5, although the wave height tends to be overestimated to some extent, the observation value corresponds well with respect to the wave period.

5.2. *Correlation comparison by domain*

Figure 8 shows the correlation between the results of the observed data and WAM of the wave height and wave period at Hitachinaka. The regression coefficient of the wave height is calculated to be 0.85and that of the wave period is 1.01.

Figure 9 shows the regression coefficients of the wave height and the wave period of the NOWPHAS points in Figure3b. With the expansion of the calculation domain, the regression coefficient of the wave height is observed to be increased, but depending on the location it may deviate greatly from 1.0. On the other hand, the regression coefficient of the wave period improves with the expansion of the domain and approaches 1.0. In the GPS buoy, the regression coefficient of the wave height and the wave period approaches 1.0 with the expansion of the area, and the accuracy has improved. Thus the tendency of the regression coefficient differs with the coastal area and this might be because of the influence of seabed topography. For example, at Hitachinaka the average wave period is about 8 seconds and the wavelength in deep water area is L_0 = 99.84 m, and at the depth of h=30.3m, the relative water depth h/L_0 is 0.30 and thus it is considered to include the influence of the ocean bed topography. In this calculation, the use of Deep Sea model of WAM has lead to the result without the influence of the seabed topography and thus causing difference in the regression coefficient of the wave height.

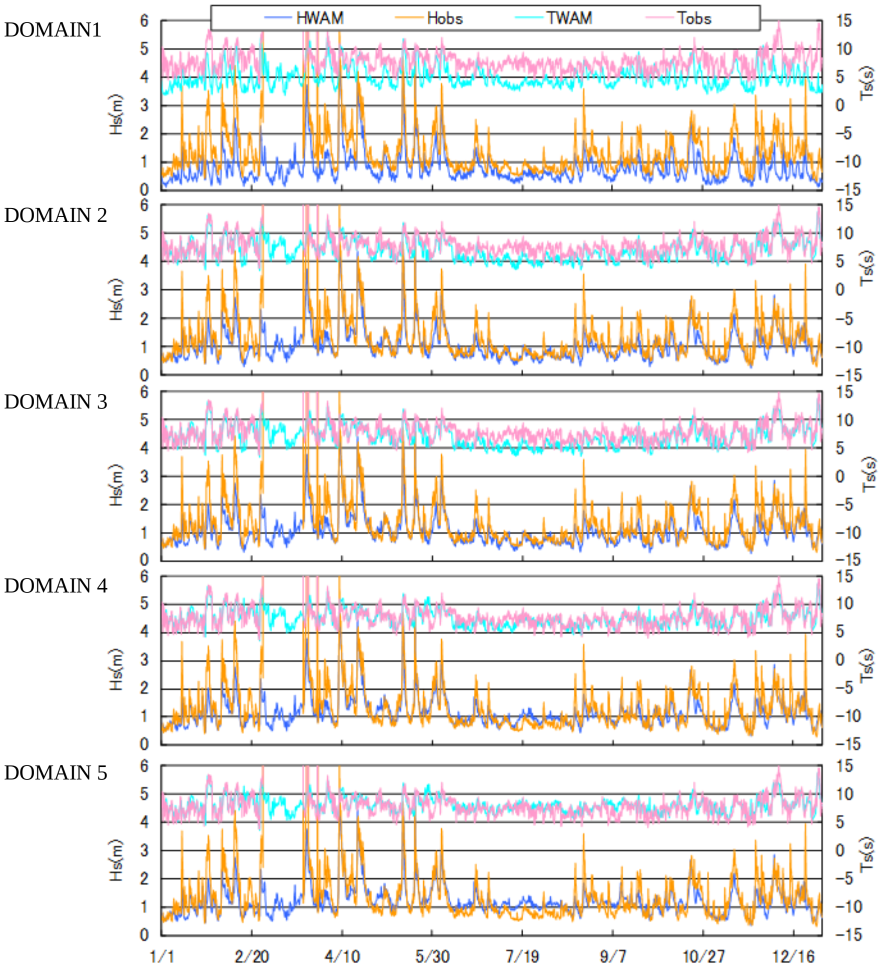
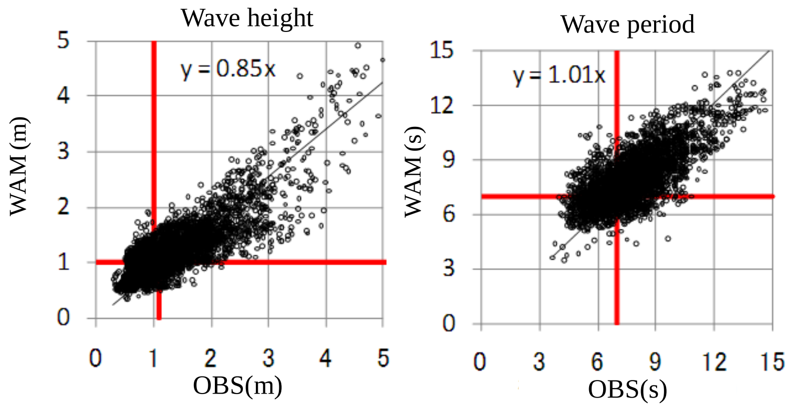
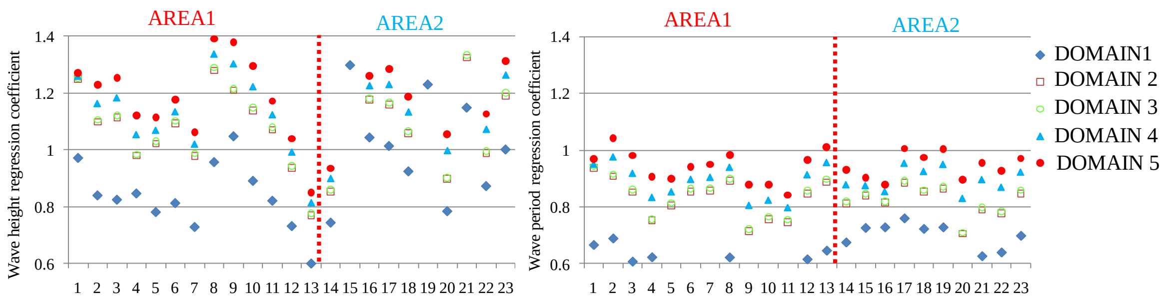


Figure 7. Time series of comparison between WAM simulation and observed data in 2008



(a) wave height correlation (b) wave period correlation

Figure 8. Correlation diagram between field observation and calculated value



(a) wave height correlation (b) wave period correlation

Figure 9. Regression coefficient between field observation and calculated value

5.3. *Operation propriety criterion and error tolerance*

The hit rate is as shown in the Figure 10. Assume the reference wave height and wave period workability is set to 1.0m and 7.0s respectively. When the WAM wave height is 1.0m or less and the observation wave height is 1.0m or less, is an operation hit; whereas when the WAM wave height is 1.0m or more and the observed wave height is 1.0m or more, is an inactive hit. In the same way, when the WAM wave period and the observation wave period are 7.0s or less is an operation hit; whereas when predicated WAM period and the observation wave period are greater than 7.0s, is an inactive hit.

In case when the WAM Model value is larger than the reference value and observed value is smaller than the reference value, the work is actually possible but it is not conducted leading to the economic risk. On contrary when the WAM model value is smaller than and the Observed value is larger than the reference value, there are possibilities of danger when work is conducted since originally the height of wave exceeds working limit. For a proper data sorting, WAM and Observation value are compared every hour and the work is conducted if and only when the WAM and observed value of wave height and period are smaller than the reference value. On the other hand when either of the both values exceeds the reference value, the work is stopped. Hit ratio is defined as the ratio of the hit/success data and all the data.

		WAM		
		$H_{1/3}$<1.0	$H_{1/3}$>=1.0	sum
Observed	$H_{1/3}$<1.0	A	B	N1 = (A+B)
	$H_{1/3}$>=1.0	C	D	N2 = (C+D)
	sum	M1 = (A+C)	M2 = (B+D)	N = (A+B+C+D)

A: Work OK Hit
B: overestimate error(economic loss)
C: underestimate error(dangerous work)
D: Work NG Hit
◆Hit ratio （A+D）/ (A+B+C+D）

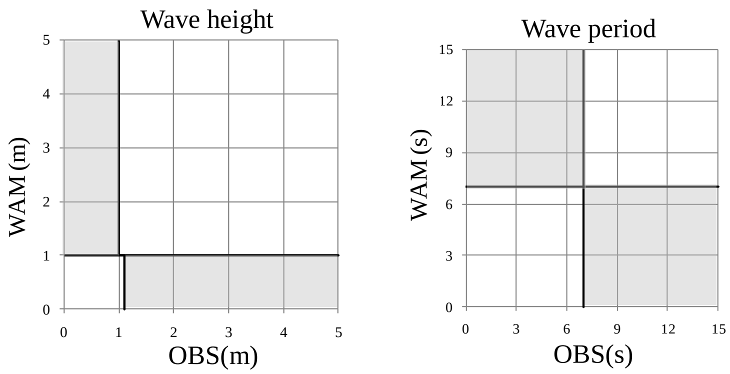


Figure 10. Definition of hit rate (wave height error tolerance + 10 cm)

5.4. *Workability hit rate*

Figure 11 shows the hit rate of change of prediction value at the NOWPHAS point (in Figure 3a). The economic risk with respect to the wave height increases and hit ratio decreases, if the calculation does not take into account the influence of the domain of smaller size and the sea bed topography. Also, since the wave period is underestimated because of the narrow area, the economic risk with respect to the wave period increases and the hit rate decreases. As a comprehensive result, broadening the area could achieve higher hit rate. But in the western Japan (area2 as shown in Figure3), the wave period is slightly shorter and thus there is no notable difference with the widening of the calculation area.

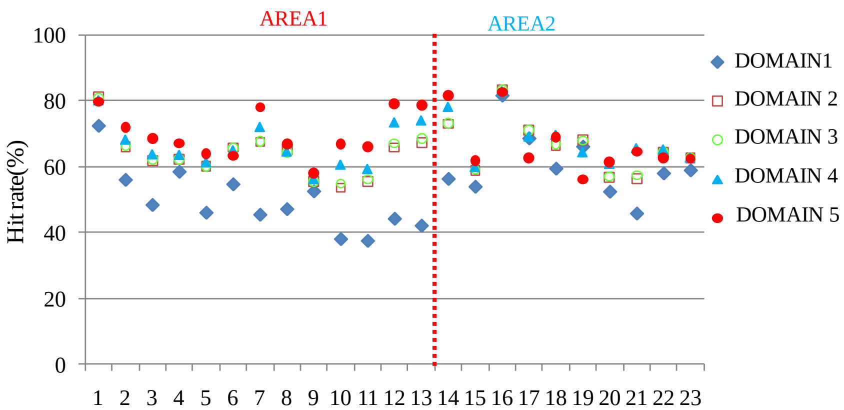


Figure 11. NOWPHAS point precession rate

5.5. *Influence of wave deformation in shallow water*

For all the points in Figure 3a, the wave deformation was calculated using the energy equilibrium formula and the shielding effect of the topography was investigated. Wave height regression coefficient and hit ratio are shown in the Figure12.

From Figure12, the accuracy is found to be improved comparatively as the wave height regression coefficient approaches to 1.0 following the indispensable evaluation of shallow water area at these points. But the remarkable improvement in the precision of the hit rate cannot be confirmed. This is because of the presence of many ports on the Pacific Side which provides no information about the wave period on one hand and the improvement in wave height accuracy has no effect on the hit rate on the other hand.

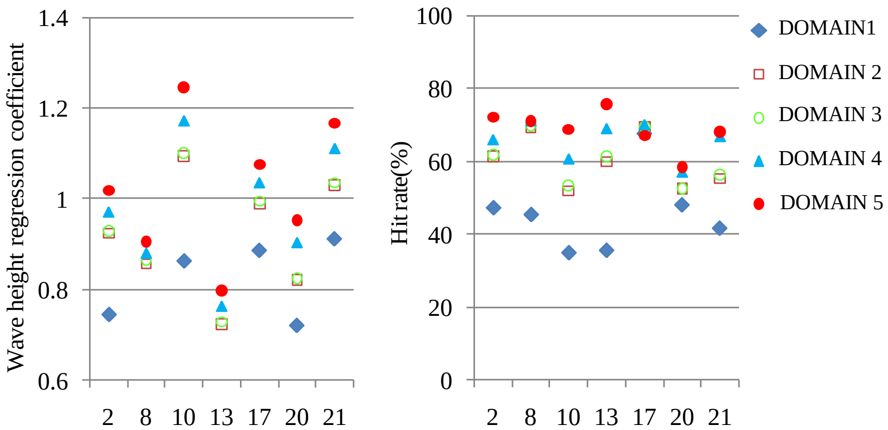


Figure 12. Wave height regression coefficient considering shallow water area, hitting ratio

6. Application to Construction Site Operation

6.1. *Outline of installation work of the Hitachi Naka Port caisson*

During the Caisson installation, at Hitachinaka port on the Pacific Ocean side, the ocean condition on the installation day and the wave prediction result are compared with the workability criteria (wave height 1.0m and wave period 7.0s).The caisson installation work period was about 2 months from June 9 2010 to August 8 2010.

6.2. *Comparison of forecast results in caisson installation period*

During the caisson installation date (a total of 4 days), the comparison between the WAM and the observed value with respect to the wave heights and wave period in domain 2 and domain 5 (in consideration with the wave deformation in shallow water area) is shown in the Figure13.

From the Figure13 it could be interpreted that at Hitachinaka, the observed value of the wave height is less than 1.0m while that of the wave period is more than 7s for many days. Thus there is a greater influence of wave period on the workability judgment. In domain2, the correspondence of the wave height by WAM and the observed value is good whereas that of the wave period is found to be underestimated as about 5s except for high wave season. This could probably increase the work risk factor. In domain5, during the high wave season the prediction accuracy of the significant wave height and wave period is high. But during the low wave season with the wave period exceeding 7s, the significant wave height is overestimated. By considering the case of Hitachinaka, if the caisson installation was done on June 27 and July 23, (i) When the calculation area is domain2, underestimation of the wave period leads to work risk, (ii) When the calculation area is domain5, the wave height is found to correspond well with the observation value and the wave period is almost found to correspond. Thus the widening of the calculation area to Domain5 could provide good judgment in the workability condition.

6.3. *Setting of calculation area*

From the analysis, it can be interpreted that the in domain 2, the workability judgment with respect to the wave height is found to be appropriate while that of the wave period is found to increase the work risk factor. Thus it can be judged that the domain 5 is more appropriate than the domain 2. The period accuracy in the domain 2 is found to increase only when the waviness is considered, but the source of the waviness is found to be outside the region. However in domain 5, there is the tendency to overestimate the wave height during the summer (confirmed in the GPS buoy). Although this factor is not clear, the swelling from the southern hemisphere has obvious influence, and hence it is necessary to study the nonlinear interaction and numerical dispersion in order to advance the wave model further.

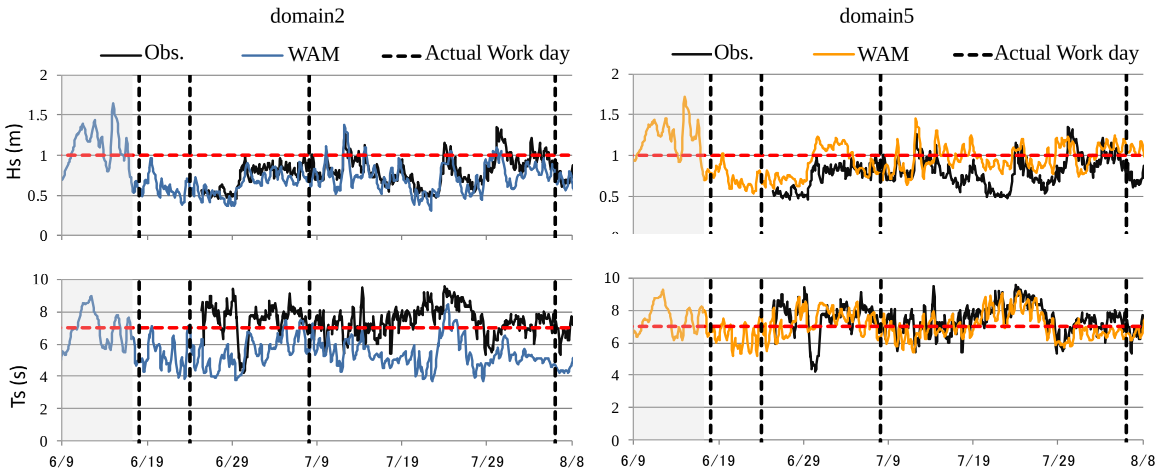


Figure.13 Comparison between WAM simulation and observation for working day judgement

7. Conclusion

The conclusion obtained is summarized as follows;

1. By widening the calculation area to the southern hemisphere, in the Pacific Ocean side, the prediction accuracy of the WAM model (inputs the wind data of Japan Meteorological Agency GPV) could be improved and the accuracy of wave height, wave period and wave direction could be expected to improve.
2. In the shallow water area, the influence of the wave deformation due to the grid size and seabed topography on the prediction accuracy is larger than the influence by the shielding of the topography and the seabed topography. So the evaluation of the wave deformation with influence of seabed topography is expected.
3. Discussion of the caisson Installation work at Hitachinaka port is an appropriate example of the comparison of wave prediction result with the coastal structure installation work. Domain2 is observed to be good, because the workability judgment is done by considering only the wave height value. But domain5 is found to be more appropriate since the workability judgment incorporates the consideration of the wave period.
4. When workability judgment is carried out using wave height and wave period, widening of the calculation area of 40°S to 70°S is found to provide good forecast for the offshore operations in the Pacific coast around Japan.

References

NOWPHAS: http://www.pari.go.jp/unit/kaisy/en/nowphas/